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MgO and 70 w% UO_2 – 30 w% Y_2O_3: Thermophysical and Transient Properties

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MgO and 70 w% UO_2 - 30 w% Y_2O_3: Thermophysical and Transient Properties

Martin Pilch

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1. Introduction

Interactions between a molten core simulant and MgO bricks (Harklase) are being studied at Sandia National Laboratories. A molten core simulant, consisting of 70 w% UO_2 and 30 w% Y_2O_3, has been proposed for use in large scale experiments (200 kg) at Sandia's Large Melt Facility. This report documents the binary phase diagrams, thermophysical properties, and transport properties which are necessary for the analysis of these experiments.

2. Binary Phase Diagrams

Figure 2.1 presents the three binary phase diagrams for the materials considered here. These phase diagrams are obtained from Levin, Robbins, and McMurdie.[8]

The molten core simulant considered here is composed of 70 w% UO_2 and 30 w% Y_2O_3.* The phase diagram for this system indicates a solidus temperature of 2753 K and a liquidus temperature of 2853 K.

3. Pure Component Properties of Solids

3.1 Melting Temperature

MgO melt temperature is given by Barin and Knacke.[1] UO_2 melt temperature data is summarized by Fink, Chasanov, and Leibowitz;[4] their recommended value is used here. Y_2O_3 melt temperature data is summarized by Foex;[6] his recommended value is used here.

Material	T_m(K)
MgO	3098
UO_2	3120
Y_2O_3	2712

3.2 Density

UO_2 density data is summarized by Fink, Chasanov, and Leibowitz.[4] Their recommended function for UO_2 density is given by Equation 3.2.1. MgO and Y_2O_3 density fits are obtained using the same functional form. MgO and Y_2O_3

*66 mole% UO_2 - 34 mole% Y_2O_3

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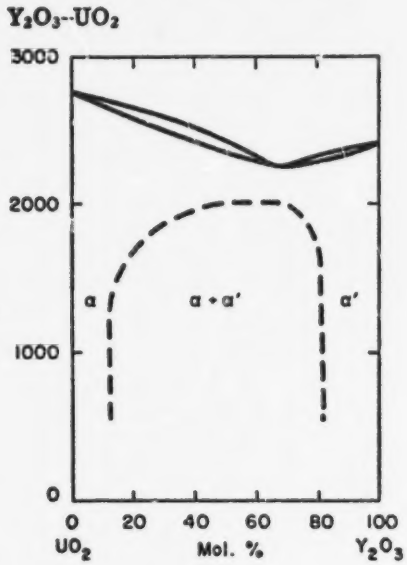

FIG. 353.—System Y_2O_3–UO_2 in reducing atmosphere.

L. E. Olds, private communication, Dec. 27, 1961.

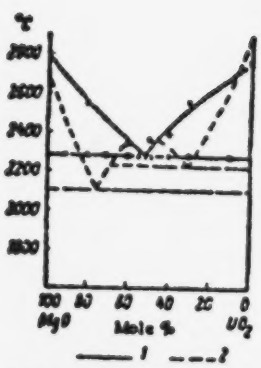

FIGURE 398. Mealised phase diagram of the system MgO – UO_2:

1 – after Buckhov et al.; 2 – after Lambertson and Mueller.

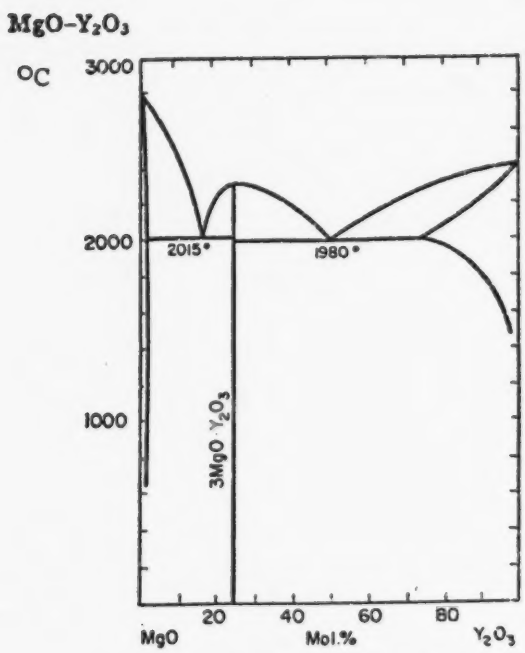

FIG. 263.—System MgO–Y_2O_3.

H. E. Otto, private communication, Dec. 27, 1961.

Figure 1: Binary Phase Diagrams

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thermal expansion data summarized by Touloukian[12,13] is transformed into density values. Room temperature density for MgO is obtained from Reference 7. Room temperature density for Y_2O_3 (100%) is obtained from Vier.[17]

$$\rho(Kg/m^3) = \frac{\rho_{Tr}}{1 + A(T - Tr) + B(T - Tr)^2} \qquad 3.2.1$$

Material	Tr	ρ_{Tr}	A	B
MgO* (p=0)	293	3570	3.58×10^{-5}	8.98×10^{-9}
MgO+ (p=17.3)	293	2870	3.58×10^{-5}	8.98×10^{-9}
UO_2	273	10970	2.04×10^{-5}	8.70×10^{-9}
Y_2O_3	293	5030	2.07×10^{-5}	4.02×10^{-9}

*MgO, 100% dense

+Harklase, 17.3% porosity

3.3 Enthalpy and Specific Heat

Barin and Knacke's[1] recommended enthalpy and specific heat functions for MgO are given by Equations 3.3.1 and 3.3.2. Y_2O_3 enthalpy data of Pankratz[10] et al. and Shpil'rain[11] et al. are fitted to the same functions.

$$H(J/Kg) - H_{Tr} = A(T - Tr) + \frac{B}{2}(T^2 - Tr^2) - C\left(\frac{1}{T} - \frac{1}{Tr}\right) \qquad 3.3.1$$

$$C_p(J/Kg/K) = A + BT + \frac{C}{T^2} \qquad 3.3.2$$

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Material	Tr	A	B	C
MgO	298	1.2153×10^{3}	7.7962×10^{-2}	-2.8382×10^{7}
Y_2O_3	298	9.7212×10^{1}	3.9925×10^{-1}	4.4352×10^{7}

Recommended enthalpy and specific heat functions for UO_2 are taken from Fink, Chasanov, and Leibowitz.[4]

$298 \leq T \leq 2670$

$$H(J/Kg) - H_{Tr} = c_1 \theta \left[(e^{\theta/T} - 1)^{-1} - (e^{\theta/Tr} - 1)^{-1} \right] + c_2 (T^2 - Tr^2) + c_3 k (T - Tr) e^{-Ea/k/T} \qquad 3.3.3$$

$$C_p(J/Kg/K) = \frac{c_1 \theta^2 \, e^{\theta/T}}{T^2 \, (e^{\theta/T} - 1)^2} + 2c_2 T + c_3 k \, e^{-Ea/k/T} \left[1 + \frac{(T - Tr) Ea}{kT^2} \right] \qquad 3.3.4$$

$Tr = 298$

$c_1 = 2.8940 \times 10^{-2}$

$c_2 = 1.4387 \times 10^{-2}$

$c_3 = 1.2758 \times 10^{8}$

$Ea = 1.8850$

$\theta = 515.16$

$k = 8.6144 \times 10^{-5}$ (Boltzman Constant)

$2670 \leq T \leq 3120$

$$H(J/Kg) - H_{298} = 6.1694 \times 10^{2} T - 8.0668 \times 10^{5} \qquad 3.3.5$$

$$Cp(J/Kg/K) = 6.1694 \times 10^{2}$$

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3.4 Heat of Fusion

MgO heat of fusion is taken from Barin and Knacke[1] while UO_2 heat of fusion is taken from Fink, Chasanov, and Leibowitz.[4] Y_2O_3 heat of fusion is obtained by subtracting the solid enthalpy (Eq. 3.3.1) from the liquid enthalpy (Eq. 4.2.1) at the melting point.

Material	h_f (J/Kg)
MgO	1.92×10^6
UO_2	2.08×10^5
Y_2O_3	4.79×10^5

3.5 Thermal Conductivity

UO_2 thermal conductivity data has been reviewed by Fink, Chasanov, and Leibowitz.[5] Their recommended function for UO_2 thermal conductivity is given by Equation 3.5.1 for $T \leq 2670K$. High temperature UO_2 thermal conductivity is given by Equation 3.5.2. Recommended MgO thermal conductivity values are taken from Touloukian[14] (corrected to 100% density) and fitted to the function recommended for UO_2. Y_2O_3 thermal conductivity data (corrected to 100% density) taken from Touloukian[17] et al., Faucher[3] et al., and Chekhovskoi[2] et al. are fitted to the recommended function for UO_2.

$$k(W/m/K) = \frac{1}{A + BT + CT^2} + DT\, e^{-E/F/T} \qquad 3.5.1$$

	MgO	UO_2 ($T \leq 2670K$)	Y_2O_3
A	1.0889×10^{-3}	6.8652×10^{-2}	-9.8425×10^{-2}
B	4.9588×10^{-5}	1.6607×10^{-4}	5.0097×10^{-4}
C	3.6446×10^{-8}	3.2749×10^{-8}	-1.2882×10^{-7}
D	8.4997×10^{-1}	1.1319×10^{-1}	8.5939×10^{-2}
E	1.0356	1.1346	1.0028
F*	8.6144×10^{-5}	8.6144×10^{-5}	8.6144×10^{-5}

*F = Boltzman Constant

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UO_2 $\quad 2670 \leq T \leq 3120$

$$k(W/m/K) = 4.0270 - 1.9149 \times 10^{-4} T \qquad 3.5.2$$

Porosity corrections[9] for MgO and Y_2O_3 are made with Equation 3.5.3.

$$k(p) = k(o)\ (1-p^{2/3}) \qquad 3.5.3$$

3.6 Thermal Diffusivity

Thermal diffusivity ($\alpha = k/\rho/C_p$) values are obtained by using the computed values for k, ρ, and C_p.

3.7 Emissivity

MgO normal total emittance data is summarized by Touloukian[16] et al. A cubic fit yields Equation 3.7.1 for temperatures below 2640K. Equation 3.7.1 yields emissivity values exceeding unity for temperatures above 2640K; an emissivity of one is assumed for temperatures above 2640K.

MgO $\quad 300 \leq T \leq 2640$

$$\varepsilon = .875 - 2.44 \times 10^{-4} T - 3.80 \times 10^{-7} T^2 + 1.86 \times 10^{-10} T^3 \qquad 3.7.1$$

MgO $\quad 2640 \leq T \leq 3098$

$$\varepsilon = 1.0 \qquad 3.72$$

UO_2 emissivity data is summarized by Fink, Chasanov, and Leibowitz.[5] Their recommended functions are given below.

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Sintered UO_2 $\quad 1000 \leq T \leq 3120$

$$\varepsilon(\lambda = .63 \text{ m}) = .87 \qquad 3.7.3$$

Premelted UO_2 $\quad 1000 \leq T \leq 3120$

$$\varepsilon(\lambda = .63 \text{ m}) = .836 + 4.321\text{x}10^{-6}\ (T-3120) \qquad 3.7.4$$

Y_2O_3 normal total emittance data is summarized by Touloukian[17] et al. The emissivity data is independent of temperature.

Y_2O_3 $\quad 300 \leq T \leq 2712$

$$\varepsilon = .30$$

4. Pure Component Properties of Liquids

4.1 Density

MgO liquid density is not currently known. An estimate is obtained by assuming $\Delta\rho/\rho = .1$ upon melting; this is typical of many materials, including UO_2. MgO liquid density obtained by this procedure is given below.

$$\rho(\text{Kg/m}^3) = 2743 \qquad 4.1.1$$

UO_2 liquid density data is summarized by Fink, Chasanov, and Leibowitz.[4] Their recommended liquid density function is given by Equation 4.1.2.

$$\rho(\text{Kg/m}^3) = \frac{8699}{1 + 9.3\text{x}10^{-5}(T-3120)} \qquad 4.1.2$$

Y_2O_3 liquid density is not currently known. The assumption applied in the MgO case is also applied here.

$$\rho(\text{Kg/m}^3) = 4217 \qquad 4.1.3$$

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4.2 Enthalpy and Specific Heat

MgO enthalpy and specific heat functions are taken from Barin and Knacke.[1] UO_2 enthalpy and specific heat data are reviewed by Fink, Chasanov, and Leibowitz;[4] their recommended function is used here. Y_2O_3 enthalpy and specific heat data are taken from Shpil'rain.[11] The enthalpy and specific heat functions for these materials are given below.

$$H(J/Kg) - H_{298} = A + B(T - Tm) \qquad 4.2.1$$

$$C_p(J/Kg/K) = B \qquad 4.2.2$$

Material	A	B	Tm
MgO	5.6079×10^6	1.5053×10^3	3098
UO_2	1.3986×10^6	4.8495×10^2	3120
Y_2O_3	2.2965×10^6	8.5983×10^2	2712

4.3 Thermal Conductivity

MgO and Y_2O_3 liquid thermal conductivity is not currently known. For lack of a better method, MgO and Y_2O_3 liquid thermal conductivity values are assumed equal to the solid thermal conductivity values at their respective melting temperature. UO_2 liquid thermal conductivity data is summarized by Fink, Chasanov, and Leibowitz;[5] their recommended value is used here.

Material	k(W/m/K)
MgO	56.3
UO_2	11.0
Y_2O_3	6.38

4.4 Thermal Diffusivity

Thermal diffusivity ($\alpha = k/\rho/C_p$) values are obtained by using the respective values for k, ρ, and C_p.

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4.5 Emissivity

MgO and Y_2O_3 liquid emissivities are not currently known. For lack of a better method, MgO and Y_2O_3 liquid emissivity values are assumed equal to the solid emissivity values at the respective melting temperature for each material.

Material	ε
MgO	1.0
Y_2O_3	.3

UO_2 liquid emissivity data is summarized by Fink, Chasanov, and Leibowitz;[5] their recommended function is used here.

$$\varepsilon(\lambda = .63\ \mu m) = 1.0 - A\ e^{B(T-Tm) + C(T-Tm)^2} \qquad 4.5.1$$

$Tm = 3120$

$A = 1.6096 \times 10^{-1}$

$B = -3.7897 \times 10^{-4}$

$C = -3.2718 \times 10^{-7}$

4.6 Viscosity

MgO and Y_2O_3 viscosities are not currently known. UO_2 viscosity data is summarized by Fink, Chasanov, and Leibowitz;[5] their recommended function is used here.

$UO_2 \qquad T \geq 3120$

$$\mu\,(Pa\ s) = 9.88 \times 10^{-4}\ e^{4620/T} \qquad 4.6.1$$

5. 70 w% UO_2 - 30 w% Y_2O_3; Solid Properties

$300 \leq T \leq 2753$

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5.1 Density

The ideal solution mixture rule for density is used here.

$$\rho_m = \frac{1}{\frac{x}{\rho_1} + \frac{1-x}{\rho_2}} \qquad 5.1.1$$

Here, x is the mass fraction of UO_2; the subscript m refers to the mixture; the subscript 1 refers to UO_2; and the subscript 2 refers to Y_2O_3.

An analytic density function is fitted to computed mixture densities obtained from Equation 5.1.1.

$$\rho_m(Kg/m^3) = \frac{\rho_{Tr}}{1 + A(T - Tr) + B(T - Tr)^2} \qquad 5.1.2$$

$Tr = 300$

$\rho_{Tr} = 8097$

$A = 2.07 \times 10^{-5}$

$B = 6.48 \times 10^{-9}$

5.2 Enthalpy and Specific Heat

The ideal solution mixture rules for enthalpy and specific heat are used here.

$$H_m = xH_1 + (1-x)H_2 \qquad 5.2.1$$

$$C_{pm} = xC_{p1} + (1-x)C_{p2} \qquad 5.2.2$$

Analytic functions are fitted to the computed mixture enthalpies and specific heats obtained from Equations 5.2.1 and 5.2.2.

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$$H_m(J/Kg) - H_{Tr} = A(T - Tr) + \frac{B}{2}(T^2 - Tr^2) - C\left(\frac{1}{T} - \frac{1}{Tr}\right) \qquad 5.2.3$$

$$C_{pm}\ (J/Kg/K) = A + BT + \frac{C}{T^2} \qquad 5.2.4$$

$Tr = 298$

$A = 1.8986 \times 10^{2}$

$B = 1.8355 \times 10^{-1}$

$C = 10^{7}$

5.3 Thermal Conductivity

A parallel circuit analogy is used to calculate mixture thermal conductivities (100% dense).

$$k_m(W/m/K) = yk_1 + (1-y)k_2 \qquad 5.3.1$$

Here, y is the UO_2 volume fraction.

$$y = x\frac{\rho_m}{\rho_1} \qquad 5.3.2$$

An analytic thermal conductivity function is fitted to computed mixture thermal conductivities obtained from Equation 5.3.1.

$$k_m(W/m/K) = \frac{1}{A + BT + CT^2} + DT\ e^{-E/F/T} \qquad 5.3.3$$

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$A = -1.4983 \times 10^{-2}$

$B = 3.4023 \times 10^{-4}$

$C = -5.5698 \times 10^{-8}$

$D = 1.1033 \times 10^{-1}$

$E = 1.1345$

$F = 8.6144 \times 10^{-5}$

5.4 Thermal Diffusivity

Thermal diffusivity ($\alpha = k/\rho/C_p$) values are obtained by using the computed values for k, ρ, and C_p.

5.5 Emissivity

The emissivity mixture rule used here is given below.

$$\varepsilon_m = y\varepsilon_1 + (1-y)\varepsilon_2 \qquad 5.5.1$$

The mixture emissivity is a weak function of temperature.

$$\varepsilon_m = .568 + 3.64 \times 10^{-6} T \qquad 5.5.2$$

6. 70 w% UO_2 - 30 w% Y_2O_3; Two Phase Properties

$2753 \leq T \leq 2853$

6.1 Density

The two phase mixture density is assumed to vary linearly between the solidus and liquidus temperatures.

$$\rho_m(Kg/m^3) = 7430 - 7.46\ (T-2753) \qquad 6.1$$

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6.2 Enthalpy and Specific Heat

The two phase mixture enthalpy is assumed to vary linearly between the solidus and liquidus temperature. The enthalpy derivative is equal to the effective specific heat for the two phase mixture.

$$H_m(J/Kg) - H_{298} = 1.18x10^6 + 4.3x10^3\ (T-2753) \qquad 6.2.1$$

$$C_{pm}(J/Kg/K) = 4300 \qquad 6.2.2$$

6.3 Thermal Conductivity

The two phase mixture thermal conductivity is assumed to vary linearly betwen the solidus and liquidus temperatures.

$$k_m\ (W/m/K) = 4.54+4.26X10^{-2}\ (T-2753) \qquad 6.3.1$$

6.4 Thermal Diffusivity

Thermal diffusivity ($\alpha = k/\rho/C_p$) values are obtained by using the computed values for k, ρ, and C_p.

6.5 Emissivity

The two phase mixture emissivity is taken as .58, the value of the solid mixture emissivity and the liquid mixture emissivity at the solidus temperature and liquidus temperature respectively.

6.6 Viscosity

The two phase mixture viscosity is not known.

7. 70 w% UO_2 - 30 w% Y_2O_3; Liquid Properties

$T \geq 2853$

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7.1 Density

The ideal solution mixture rule (Equation 5.1.1) for density is also used for the liquid phase; however, ρ_1 and ρ_2 are now the liquid densities. The UO_2 liquid density is obtained by extrapolation for temperatures below its (pure component) melting point (3120 K).

An analytic density function is fitted to computed mixture densities obtained from this procedure.

$$\rho_m(Kg/m^3) = \frac{6684}{1 + 5.00x10^{-5}\ (T-2853)} \qquad 7.1.1$$

7.2 Enthalpy and Specific Heat

The ideal solution mixture rules for enthalpy (Equation 5.2.1) and specific heat (Equation 5.2.2) are also used for the liquid phase. Liquid properties below the pure component melting temperatures are obtained by extrapolation.

Analytic enthalpy and specific heat functions are fit to the computed properties obtained from this procedure.

$$H_m(J/Kg) - H_{298} = 1.6140x10^6 + 5.9759x10^2\ (T-2853) \qquad 7.2.1$$

$$C_{pm}(J/Kg/K) = 598 \qquad 7.2.2$$

7.3 Thermal Conductivity

A parallel circuit analogy (Equation 5.3.1) is also used to calculate liquid thermal conductivities for the mixture. An analytic function is fitted to the computed mixture thermal conductivities obtained from this procedure.

$$k_m(W/m/K) = 8.80 + 1.05x10^{-4}\ (T-2853) \qquad 7.3.1$$

7.4 Thermal Diffusivity

Thermal diffusivity ($\alpha = k/\rho/C_p$) values are obtained by using the computed values for k, ρ, and C_p.

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7.5 Emissivity

The emissivity mixture rule (Equation 5.5.1) based on volume averaging is also used for the liquid phase.

An analytic function is fitted to the computed mixture emissivities obtained from this procedure.

$$\varepsilon_m = .58 + 4.22\text{x}10^{-5} \ (T-2853) \qquad 7.5.1$$

7.6 Viscosity

Y_2O_3 viscosity is not known; therefore, mixture viscosities cannot be computed. Lacking a better method, the mixture vixcosity is assumed equal to the viscosity of pure UO_2.

$$\mu_m(\text{Pa.s}) = 9.88\text{x}10^{-4} \ e^{4620/T} \qquad 7.6.1$$

8. Tabulated Properties

See following pages 16 through 20.

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MgO (100% dense) Thermophysical and Transport Properties

T (K)	ρ (Kg/m^3)	$H-H_{298}$ (J/Kg)	C_p (J/Kg/K)	k (W/m/K)	α (m/s^2)	ε	μ (Pa s)
400	3556	1.024×10^5	1069	37.4	9.84×10^{-6}	.73	
600	3528	3.297×10^5	1183	22.8	5.46×10^{-6}	.63	
800	3498	5.718×10^5	1233	15.6	3.62×10^{-6}	.53	
1000	3467	8.218×10^5	1265	11.5	2.62×10^{-6}	.44	
1200	3433	1.077×10^6	1289	8.89	2.01×10^{-6}	.36	
1400	3398	1.337×10^6	1310	7.27	1.63×10^{-6}	.30	
1600	3361	1.601×10^6	1329	6.50	1.46×10^{-6}	.27	
1800	3323	1.869×10^6	1347	6.72	1.50×10^{-6}	.29	
2000	3283	2.140×10^6	1364	8.23	1.84×10^{-6}	.36	
2200	3243	2.414×10^6	1381	11.4	2.54×10^{-6}	.48	
2400	3201	2.692×10^6	1397	16.7	3.73×10^{-6}	.67	
2600	3158	2.973×10^6	1414	24.4	5.46×10^{-6}	.94	
2800	3115	3.258×10^6	1430	34.9	7.83×10^{-6}	1.0	
3000	3070	3.545×10^6	1446	48.5	1.09×10^{-5}	1.0	
3098	3048	3.687×10^6	1454	56.3	1.27×10^{-5}	1.0	
3098	2743	5.608×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3200	2743	5.761×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3400	2743	6.063×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3600	2743	6.364×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3800	2743	6.665×10^6	1505	56.3	1.36×10^{-5}	1.0	---
4000	2743	6.966×10^6	1505	56.3	1.36×10^{-5}	1.0	---

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Harklase (MgO, 82.7% dense) Thermophysical and Transport Properties

T (K)	ρ (Kg/m^3)	$H-H_{298}$ (J/Kg)	C_p (J/Kg/K)	k (W/m/K)	α (m/s^2)	ε	μ (Pa s)
400	2859	1.024×10^5	1069	25.8	8.44×10^{-6}	.73	
600	2836	3.297×10^5	1183	15.7	4.68×10^{-6}	.63	
800	2812	5.718×10^5	1233	10.8	3.11×10^{-6}	.53	
1000	2787	8.218×10^5	1265	7.92	2.25×10^{-6}	.44	
1200	2760	1.077×10^6	1289	6.13	1.72×10^{-6}	.36	
1400	2732	1.337×10^6	1310	5.01	1.40×10^{-6}	.30	
1600	2702	1.601×10^6	1329	4.48	1.25×10^{-6}	.27	
1800	2671	1.869×10^6	1347	4.64	1.29×10^{-6}	.29	
2000	2640	2.140×10^6	1364	5.68	1.58×10^{-6}	.36	
2200	2607	2.414×10^6	1381	7.87	2.19×10^{-6}	.48	
2400	2573	2.692×10^6	1397	11.5	3.20×10^{-6}	.67	
2600	2539	2.973×10^6	1414	16.8	4.68×10^{-6}	.94	
2800	2504	3.258×10^6	1430	24.0	6.70×10^{-6}	1.0	
3000	2468	3.545×10^6	1446	33.4	9.36×10^{-6}	1.0	
3098	2451	3.687×10^6	1454	38.9	1.09×10^{-5}	1.0	
3098	2743	5.608×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3200	2743	5.761×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3400	2743	6.063×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3600	2743	6.364×10^6	1505	56.3	1.36×10^{-5}	1.0	---
3800	2743	6.665×10^6	1505	56.3	1.36×10^{-5}	1.0	---
4000	2743	6.966×10^6	1505	56.3	1.36×10^{-5}	1.0	---

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UO_2 Thermophysical and Transport Properties

T (K)	ρ (Kg/m^3)	$H-H_{298}$ (J/Kg)	C_p (J/Kg/K)	k (W/m/K)	α (m/s^2)	ε	μ (Pa s)
400	10940	2.564×10^4	264	7.13	2.47×10^{-6}	.82	
600	10887	8.136×10^4	290	5.55	1.76×10^{-6}	.83	
800	10827	1.407×10^5	303	4.50	1.36×10^{-6}	.83	
1000	10761	2.022×10^5	312	3.74	1.11×10^{-6}	.83	
1200	10688	2.653×10^5	320	3.18	9.30×10^{-7}	.83	
1400	10609	3.299×10^5	327	2.75	7.94×10^{-7}	.83	
1600	10524	3.959×10^5	334	2.44	6.93×10^{-7}	.83	
1800	10433	4.640×10^5	346	2.25	6.23×10^{-7}	.83	
2000	10338	5.348×10^5	365	2.19	5.80×10^{-7}	.83	
2200	10237	6.144×10^5	402	2.31	5.62×10^{-7}	.83	
2400	10132	6.973×10^5	466	2.65	5.61×10^{-7}	.83	
2600	10022	8.003×10^5	569	3.24	5.69×10^{-7}	.83	
2800	9909	9.206×10^5	617	3.49	5.70×10^{-7}	.83	
3000	9792	1.044×10^6	617	3.45	5.70×10^{-7}	.84	
3120	9720	1.118×10^6	617	3.43	5.70×10^{-7}	.84	
3120	8699	1.399×10^6	485	11.0	2.61×10^{-6}	.84	4.34×10^{-3}
3200	8635	1.437×10^6	485	11.0	2.63×10^{-6}	.84	4.19×10^{-3}
3400	8478	1.534×10^6	485	11.0	2.68×10^{-6}	.86	3.84×10^{-3}
3600	8327	1.631×10^6	485	11.0	2.72×10^{-6}	.88	3.57×10^{-3}
3800	8182	1.728×10^6	485	11.0	2.77×10^{-6}	.89	3.33×10^{-3}
4000	8041	1.825×10^6	485	11.0	2.82×10^{-6}	.91	3.14×10^{-3}

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Y_2O_3 Thermophysical and Transport Properties

T (K)	ρ (Kg/m^3)	$H-H_{298}$ (J/Kg)	C_p (J/Kg/K)	k (W/m/K)	α (m/s^2)	ε	μ (Pa s)
400	5019	6.208×10^4	534	12.3	4.59×10^{-6}	.3	
600	4996	1.584×10^5	460	6.42	2.79×10^{-6}	.3	
800	4973	2.522×10^5	486	4.55	1.88×10^{-6}	.3	
1000	4948	3.546×10^5	541	3.65	1.36×10^{-6}	.3	
1200	4921	4.693×10^5	607	3.16	1.06×10^{-6}	.3	
1400	4894	5.978×10^5	679	2.88	8.67×10^{-7}	.3	
1600	4865	7.410×10^5	753	2.77	7.56×10^{-7}	.3	
1800	4835	8.296×10^5	830	2.83	7.05×10^{-7}	.3	
2000	4804	1.073×10^6	907	3.09	7.09×10^{-7}	.3	
2200	4772	1.262×10^6	985	3.58	7.62×10^{-7}	.3	
2400	4739	1.467×10^6	1063	4.38	8.70×10^{-7}	.3	
2600	4705	1.687×10^6	1142	5.54	1.03×10^{-6}	.3	
2712	4685	1.818×10^6	1186	6.38	1.15×10^{-6}	.3	
2712	4217	2.297×10^6	860	6.38	10^{-6}	.3	---
2800	4217	2.372×10^6	860	6.38	10^{-6}	.3	---
3000	4217	2.544×10^6	860	6.38	10^{-6}	.3	---
3200	4217	2.716×10^6	860	6.38	10^{-6}	.3	---
3400	4217	2.888×10^6	860	6.38	10^{-6}	.3	---
3600	4217	3.060×10^6	860	6.38	10^{-6}	.3	---
3800	4217	3.232×10^6	860	6.38	10^{-6}	.3	---
4000	4217	3.404×10^6	860	6.38	10^{-6}	.3	---

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70 w% UO_2 - 30 w% Y_2O_3 Thermophysical and Transport Properties

T (K)	ρ (Kg/m^3)	$H-H_{298}$ (J/Kg)	C_p (J/Kg/K)	k (W/m/K)	α (m/s^2)	ε	μ (Pa s)
400	8080	$3.65x10^4$	326	8.94	$3.39x10^{-6}$	.57	
600	8040	$1.05x10^5$	328	5.94	$2.25x10^{-6}$	.57	
800	8000	$1.74x10^5$	352	4.52	$1.61x10^{-6}$	.57	
1000	7960	$2.48x10^5$	383	3.70	$1.21x10^{-6}$	.57	
1200	7910	$3.27x10^5$	417	3.17	$9.61x10^{-7}$	.57	
1400	7860	$4.10x10^5$	452	2.81	$7.91x10^{-7}$	.57	
1600	7800	$5.00x10^5$	487	2.59	$6.82x10^{-7}$	.58	
1800	7740	$5.95x10^5$	523	2.49	$6.15x10^{-7}$	.58	
2000	7680	$6.96x10^5$	560	2.55	$5.93x10^{-7}$	.58	
2200	7620	$8.07x10^5$	596	2.79	$6.14x10^{-7}$	.58	
2400	7550	$9.28x10^5$	632	3.27	$6.85x10^{-7}$	.58	
2600	7480	$1.07x10^6$	669	4.04	$8.07x10^{-7}$	.58	
2753	7430	$1.18x10^6$	697	4.54	$8.77x10^{-7}$	.58	
2753	7430	$1.18x10^6$	4300	4.54	$1.42x10^{-7}$	.58	---
2800	7079	$1.38x10^6$	4300	6.54	$2.15x10^{-7}$	.58	---
2853	6684	$1.61x10^6$	4300	8.80	$3.06x10^{-7}$	.58	---

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70 w% UO_2 - 30 w% Y_2O_3 Thermophysical and Transport Properties (cont'd)

2853	6684	1.61×10^{6}	598	8.80	2.20×10^{-6}	.58	4.99×10^{-3}
3000	6635	1.70×10^{6}	598	8.82	2.22×10^{-6}	.59	4.61×10^{-3}
3200	6570	1.82×10^{6}	598	8.84	2.25×10^{-6}	.59	4.19×10^{-3}
3400	6506	1.94×10^{6}	598	8.86	2.28×10^{-6}	.60	3.84×10^{-3}
3600	6443	2.06×10^{6}	598	8.88	2.30×10^{-6}	.61	3.57×10^{-3}
3800	6382	2.18×10^{6}	598	8.90	2.33×10^{-6}	.62	3.33×10^{-3}
4000	6321	2.30×10^{6}	598	8.92	2.36×10^{-6}	.63	3.14×10^{-3}

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